Technical Report MXX

SEDIMENTATION STUDY OF THE MIDDLE MISSISSIPPI RIVER AT HERCULANEUM, MISSOURI RIVER MILES 156.3 TO 149.7

HYDRAULIC MICRO MODEL INVESTIGATION

By
Michael T. Rodgers
Dawn M. Lamm
Edward H. Riiff
Robert D. Davinroy

U.S. ARMY CORPS OF ENGINEERS
ST. LOUIS DISTRICT
HYDROLOGIC AND HYDRAULICS BRANCH
APPLIED RIVER ENGINEERING CENTER
FOOT OF ARSENAL STREET
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INTRODUCTION

The U.S. Army Corps of Engineers, St. Louis District initiated a study of the Middle Mississippi River between Miles 156.3 and 149.7 near Herculaneum, Missouri. The purpose of the study was to evaluate environmental design alternatives for the development of side channel and island habitat, utilizing an existing dike field on the Mississippi River.

Mr. Michael T. Rodgers, hydraulic engineer, and Mr. Edward H. Riff, engineering technician, under direct supervision of Mrs. Dawn M. Lamm, Hydraulic Engineer, Mr. David C. Gordon, Hydraulic Engineer and Mr. Robert D. Davinroy, District Potamologist, conducted the study between December 2002 and May 2003. Other personnel also involved with the study included: Mr. Stephen Redington and Mr. Leonard Hopkins from the River Engineering Unit of the Hydrologic and Hydraulics Branch; Mr. T. Miller, Mr. Brian Johnson, and Mr. Eric Laux from the Environmental Branch of the Planning, Programs, and Project Management Division; Mr. Mike Thompson of the Project Management Division; and Mr. Gary Lee of the Engineering Division, Design Branch. Personnel from other agencies involved in the study included: Mr. Scott Stuewe and Mr. Butch Atwood from the Illinois Department of Natural Resources, and Ms. Joyce Collins, Ms. Karen Westphal, Mr. Mike Thomas and Mr. John Magera from the U.S. Fish and Wildlife Service, and Ms. Valerie Barko from the Missouri Department of Conservation.

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BACKGROUND

Micro modeling methodology was used to evaluate sediment transport conditions as well as the impact of various structural alternatives along the Herculaneum Reach of the Middle Mississippi River. This study was funded as part of the Environmental Management Program of the U. S. Army Corps of Engineers, St. Louis District.

The primary goal of this study was to diversify aquatic habitat by modifying present dike structures, developing new side channels and bar formations while maintaining the integrity of the navigation channel.

1. Study Reach

The study reach was located approximately 30 miles south of St. Louis, Missouri. The study comprised a 7-mile stretch of the Middle Mississippi River, between Miles 156.3 and 149.7. Plate 1 is a location and vicinity map of the study reach. The study area was located in Jefferson County in Missouri, and Monroe County in Illinois. The reach was in the southern portion of the greater St. Louis Harbor, which is an important fleeting area for a large number of terminal facilities located in the St. Louis area.

Plate 2 is a 2002 aerial photograph illustrating the planform and nomenclature of the Middle Mississippi River between Miles 156.3 and 149.7. The right descending bank (RDB) consists of limestone bluffs. The bluffs are approximately 300 feet tall and act as a natural revetment to the channel. Joachim Creek is located near Mile 151.5 R. Adjacent to the left descending bank (LDB) is a large floodplain. The floodplain consists of sand, silts and clays with an occasional sedimentary rock outcrop. Fountain Creek is located near Mile 156.3 L.

At the time of this study, the Herculaneum reach included four dike fields, containing a total of twenty-nine structures. All dike structures were of stone construction.

Dike Field 1 was located along the LDB and contained 15 dikes as shown on Plate 3. The dikes were located at Miles 156.3L, 156.0L, 155.6L, 155.3L, 154.9L, 154.6L, 154.4L, 153.6L, 153.0L, 152.5L, 152.1L, 151.3L, 151.0L, 150.7L and 150.0L. Structure lengths ranged from 300 feet to 840 feet.

Dike Field 2 was located along the RDB and contained 4 dikes as shown on Plate 3. The dikes were located at Miles 154.0R, 153.7R, 153.5R and 153.1R. Structure lengths ranged from 440 feet to 540 feet.

Dike Field 3 was located along the RDB and contained 3 dikes as shown on Plate 3. The dikes were located at Miles 151.8R, 151.5R and 151.3R. Structure lengths ranged from 300 feet to 330 feet.

Dike Field 4 was located along the RDB and contained 4 dikes as shown on Plate 3. The dikes were located at Miles 150.6R, 150.4R, 150.2R, 150.0R and 149.7R. Structure lengths ranged from 200 feet to 360 feet.

The settling of airborne lead particles in sediment at from the Doe Run Lead Plant, located along the right descending bank near Mile 152, may cause adverse environmental affects. Therefore, Dike Field 3, Dikes 151.8R, 151.5R and 151.3R, are unlikely to be altered at this time in an effort to keep the lead particles localized to this section of the study reach.

The following table details the specific dimensions and characteristics of the Herculaneum Dikes. (Note: All bed elevations described in this report are referenced to the Low Water Reference Plane (LWRP). The LWRP represents a theoretical water surface elevation profile based upon a low flow of 54,000 cfs. The reference elevation of 0 feet LWRP is based upon the probability that this stage and flow will be exceeded 97% of the time annually.)

Dike/Mile	**Elevation (Feet Above LWRP)**	**Dike Length**	**Dike/Mile**	**Elevation (Feet Above LWRP)**	**Dike Length**
156.3L	16	400	154.0R	16	440
156.0L	16	420	153.7R	14	470
155.6L	11	360	153.5R	13	500
155.3L	14	450	153.1R	17	540
154.9L	13	420	151.8R	16	320
154.6L	14	300	151.5R	16	330
154.4L	16	410	151.3R	16	300
154.1L	16	360	150.6R	18	240
153.9L	15	310	150.4R	20	300
153.6L	14	570	150.2R	15	240
153.0L	13	490	150.0R	19	200
152.5L	16	530	149.7R	18	360
152.1L	13	780			
151.3L	14	840			
151.0L	15	780			
150.7L	14	590			
150.0L	17	640			

Problem Description

The limestone bluffs along RDB and dike structures along the LDB contract this reach of the Middle Mississippi River to form a uniformly deep and narrow channel. The contracted channel is excellent for navigation purposes. However, more aquatic habitat diversity is desired throughout the reach. Fish species thrive in slow, shallow channels, deep pools and around bar formations. This type of habitat may be developed from the alteration of existing dikes, i.e. notching, increasing or decreasing length and height, or by adding new dikes, or by a combination of either/or.

3. History

1880

A historical look at the Herculaneum reach of the Middle Mississippi River revealed that the channel contained a different alignment 120 years ago. According to the 1880 topographic and hydrographic map (Plate 4), the channel was wider and contained several bars, including a large bar (Lucas Bar) from Miles 152.3 to 151.0. The bars mainly consisted of fine sands and silts. Pile dike structures were placed along LDB from Miles 156 to 153 to contract the river and direct the channel around Lucas Bar. The thalweg was located in the center of the channel along the upper portion of the reach, migrated to the RDB in the middle portion of the reach, and moved back to the center of the channel along the lower part of the reach.

1908

Additional pile structures were put in place, primarily along the LDB through the Herculaneum Reach, from 1880 until 1889. This stabilized the LDB and resulted in the formation of the “modern day” Mississippi River for the Herculaneum Reach (Plate 5). Lucas Bar and several other bars eventually became part of the floodplain. A few sand bars appeared in the center of the channel and along LDB between river Miles 155 and 154. The large sand bar along RDB near Mile 150 was still evident. The thalweg was located along RDB throughout this stretch of the river.

1929

Plate 6 is a 1929 aerial photograph of the Herculaneum reach. The river alignment has remained relatively stable since 1908. The thalweg appeared to be located along the RDB throughout the study reach. The photograph also indicated future locations for dikes along the LDB.

1959

The 1959 hydrographic survey is shown on Plate 7. This survey showed the channel following the present channel alignment. The thalweg began along RDB near Mile 156.3, shifted to the LDB near Mile 154, shifted back to the RDB near Mile 152 and stayed along the RDB for the remainder of the reach. The main difference between the 1929 channel and the 1959 channel was the magnitude of shoaling on the 1958 survey. The increased shoaling was seen along LDB from Miles 156 to 154, Miles 153 to 149 and along RDB from Miles 154 to 153 and 150 to 149. The additional shoaling was caused from new dike construction designed to contract the river to increase channel depth for navigation purposes.

1969 Prototype Reach

The Herculaneum reach is part of the original “prototype reach” which is located from Mile 154.0 to Mile 140.0. Established in 1969, the ”prototype reach” is a reach of river where the channel was contracted to maintain a nine feet navigation channel during low flow periods. This was accomplished by converting seventeen pile dikes to stone-fill dikes, extending nineteen existing stone-fill dikes and constructing fifteen new stone-fill dikes to form a 1,200 feet contraction width. The contraction of the channel along the “prototype reach” has been successful in eliminating the need for dredging along this portion of the river.

1970

The 1970 hydrographic survey is shown on Plate 8. This was the first survey available after several timber pile structures were converted to stone in 1964. This process was necessary due to the short life span of timber structures on the open

river. Floods, ice and floating drift extensively damaged timber pile structures and in many cases the life span of the structures were short. The location of the thalweg in this survey was similar to the 1959 survey. The change observed between the 1959 and 1970 bathymetry was the scouring that occurred behind dikes 153.9L, 152.5L, 152.0L and 150.0L. This can be attributed to the newly formed stone filled dikes, which did not fail during high water levels allowing water to flow over them, creating plunge pools immediately downstream and parallel to the structures.

1978

The 1978 hydrographic survey is shown on Plate 9. The bathymetry of this survey was similar to the 1970 survey. The main change in bathymetry was additional aggradation within this reach. All of the previous scour holes located along backside of dikes were filled in and shoaling existed along RDB near Mile 154.1 and along the LDB from Mile 153.0 to Mile 152.0. The overall deposition was associated with decreased energy in the system, due to low water stages. The location of the thalweg remained consistent with the prior surveys.

1983

The 1983 hydrographic survey is shown on Plate 10. The bathymetry of this survey was slightly different from the 1978 survey. Scouring along backside of dikes was again evident as well as an increased shoaling area near Mile 154. The thalweg location was similar to all previous hydrographic surveys.

1987

The 1987 hydrographic survey is shown on Plate 11. This survey showed overall increase in depths throughout the reach. Increased scouring behind the dikes, (Dikes 152.5L, 152.0L, 151.3L 151.0 and 150.7L), areas of shoaling eroded away (RDB near Mile 154 and LDB near Mile 152.8), and overall increased channel depth all occurred. The degradation can be attributed to the increased energy in the system associated with the flood event of 1986. The location of the thalweg remained consistent with past hydrographic surveys.

1995

The 1995 hydrographic survey is shown on Plate 12. The bathymetry of this survey was similar to the 1987 survey. This can be attributed to the flood event of 1993. Increased energy in the system at floodwater stages caused degradation within this reach, comparable to the affects of the 1986 flood. The thalweg location is similar to the previous hydrographic surveys.

2002

The 2002 hydrographic sweep survey is shown on Plate 13. The bathymetry was consistent with past hydrographic surveys. The thalweg has remained comparable in location to previous surveys.

Additional Aerial Photos

Additional aerial photos including 1974,1988, 1993, and 1996 (Plates 14 through 17) were also used to determine any topographic or channel alignment changes over the years.

Reviewing the historical hydrographic surveys and aerial photos and comparing them to the more modern day surveys indicated the channel reached equilibrium after the transformation of timber pile dikes to stone filled dikes. Through the past forty years, including periodic flood events, the channel alignment has remained fairly consistent. Therefore, any design alternatives chosen for this project should have a lasting affect.

4. Study Purpose and Goals

The purpose of this study was to design structural modifications to the existing Herculaneum Dike Field to enhance the aquatic habitat diversity and flow dynamics within the reach. The study was performed to address two separate sediment transport goals. The first goal was to create island and side channel aquatic habitat

within the dike field. The second goal was to maintain current depths in the navigation channel to assure the need for dredging would not arise.

5. Field Observations

Personnel from the Applied River Engineering Center inspected the study reach by both helicopter and shallow draft boat. These reconnaissance missions allowed the site to be photographed and studied. The site visit is described below with the water surface elevation referenced to LWRP at the St. Louis, Missouri gage.

-3.6 LWRP (January 30, 2003)

The study reach was first visited by helicopter to video-record bank line, dike and channel conditions. At this stage, the crowns of all dikes within the study reach were visible above the water surface. Plates18 through 22 are photographs taken of the dikes within the study reach.

+19.8 feet LWRP (May 6, 2003)

Field observations were recorded and data was collected in this study reach by boat. At the time of data collection, all of the dikes were submerged by an average of 7 feet. The data collected during this site visit included sediment samples, velocity profiles and general field observations.

This reach was composed of two totally different planforms. The RDB consisted of vertical limestone bluffs (Plate 23). These bluffs acted as a natural embankment, not allowing the river to meander. Portions of this bank line were also reveted with debris from the bluffs. A series of sediment samples that were taken off the RDB indicated that the river bottom was composed of rock, clays and fine slit. Profiles revealed that the average velocity along the RDB was 3.1 ft/sec. These profiles were taken behind submerged dikes (Plate 24) and did not reflect the velocity of the thalweg.

The second planform, a floodplain, was located adjacent to the LDB. The floodplain was composed mostly of silts and clays. No portion of the LDB was reveted along this reach. However, scour holes formed behind dikes and deposited bottom material i.e. sand, along the bank line (Plate 25). These sands were represented in a series of sediment samples that were taken off the LDB. Velocity profiles taken behind submerged dikes (Plate 26) showed average velocities to be 3.4 ft/sec. These profiles do not reflect velocities of the thalweg.

MICRO MODEL DESCRIPTION

1. Scales and Bed Materials

In order to investigate the sediment transport issues and habitat development described previously, a physical hydraulic micro model was designed and constructed. Plate 27 is a photograph of the hydraulic micro model used in this study. The model employed a horizontal scale of 1 inch = 600 feet, or 1:7200, and a vertical scale of 1 inch = 100 feet, or 1:1200, for a 6 to 1 distortion ratio of linear scales. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to those of the prototype. The bed material was granular polyester urea, Type II, with a specific gravity of 1.47.

2. Appurtenances

The micro model insert was constructed according to the 1998 high-resolution aerial photography of the study reach. The insert was then mounted in a standard micro model hydraulic flume. The riverbanks of the model were constructed from dense polystyrene foam, and modified during calibration with oil-based clay. River training structures in the model were made of galvanized steel mesh.

Flow into the model was regulated by customized computer hardware and software interfaced with an electronic control valve and submersible pump. This interface was used to automatically control the flow of water and sediment into the model. Discharge was monitored by a magnetic flow meter interfaced with the customized computer software. Water stages were manually checked with a mechanical three-dimensional point digitizer. Resultant bed configurations were measured and recorded with a three-dimensional laser digitizer.

MICRO MODEL TESTS

1. Model Calibration

The calibration of the micro model involved the adjustment of water discharge, sediment volume, model slope, and entrance conditions of the model. These parameters were refined until the measured bed response of the model was similar to that of the prototype.

A. Micro Model Operation

In all model tests, a standard repeatable discharge hydrograph was simulated in the channel. This hydrograph served as the average design energy response of the river. Due to constant variation experienced in the prototype, this standard hydrograph was used to theoretically analyze the ultimate expected sediment response. Each hydrograph simulated a discharge range between extreme low flow to high "within-channel" flow. (Flow rates in the model ranged between 1.0 to 2.1 gallons per minute.) The most important factors during the modeling process are the establishment of an equilibrium condition of sediment transport and the simulation of high and low energy conditions. High flow in the model simulated a peak energy condition representative of the river feets bed forming flow and sediment transport potential at bankfull conditions. The time increment or duration of each hydrograph cycle (peak to peak) was four minutes.

B. Prototype Data and Observations

To determine the general bathymetric characteristics and sediment response trends that existed in the prototype, several present and historic hydrographic surveys were examined. Plates 7 through 12 are plan view hydrographic survey maps of the Mississippi River from 1959, 1970, 1978, 1983, 1987 and 1995 respectively. A 2002 detailed channel sweep survey of the study reach, between Miles 156.3 and 149.7 is shown on Plate 13. In the latest surveys, the thalweg of the main channel was located in the same general alignment.

The bathymetry of the most recent prototype surveys (1995 and 2002) were very similar to each other and were used to calibrate the micro model. Depths below –15 feet LWRP were maintained in the thalweg throughout the study reach, with some areas experiencing depths below –20 feet and –30 feet LWRP. At the study reach entrance, the thalweg was located along the RDB until Mile 154.3, with depths between –14 feet and –30 feet LWRP. The thalweg then crossed to the LDB, with depths below –16 feet LWRP. The thalweg remained along the LDB for approximately 1.5 miles with depths below –16 feet LWRP. Near Mile 153.0 the thalweg crossed back again to the RDB, with depths below –16 feet LWRP. The channel remained along the RDB until Mile 149.7.

Dike Field 1 contained a significant shoal located along LDB from Miles 156.0 to 154.6. This dike field contained scour holes off Dikes 154.4 L, 154.1, 153.9 L, 153.6 L, 153.0 L, 152.5 L, 152.1 L, 151.3 L, 151.0 L, 150.7, and 150.0L. The holes varied in depth, between –32 feet and –58 feet. These scour holes were observed on both surveys.

Dike Field 2 was located in the middle of the reach along RDB. Dikes 154.0 R, 153.7 R, 153.5 R and 153.1 R had limited scour associated with them.

The location of Dike Field 3 was at the lower end of the RDB and consisted of three dikes. Some scour occurred around Dikes 151.8 R, 151.5 R and 151.3 R.

Dike Field 4 contained Dikes 150.6 R, 150.4 R, 150.2 R, 150.0 R and 149.7 R. Minor scour was evident along this dike field.

2. Base Test

Model calibration was achieved once it was determined through qualitative comparisons that the prototype surveys were similar to several surveys of the model. The resultant bathymetry of this calibrated bed response served as the base test of

the micro model (Plate 28). This base test survey served as the comparative bathymetry for all design alternative tests.

Results of the micro model base test and a comparison to the 1995 and 2002 hydrographic surveys indicated the following trends.

A scour holed developed in the model off the right descending bank near Mile 158.2, with depths greater than –30 feet LWRP. The thalweg then remained along the RDB, between Mile 158.2 and Mile 154.6, with depths greater than –20 feet LWRP. Both of these trends were similar to the hydrographic surveys.

A crossing developed in the model, between Mile 154.6 R and Mile 153.9 L, which was very similar to the hydrographic surveys. Depths in the model and in the surveys were between –10 feet and –20 feet LWRP. The thalweg remained along the right descending bank until Mile 151.0, where a final crossing developed, which was also evident on the hydrographic surveys. In the model, a scour hole developed near Mile 151.9 R, with depths near –30 feet LWRP. This was approximately 10 feet greater than what was observed on the hydrographic surveys.

In the depositional areas along the study reach within the dike fields located on both sides of the river, the alignment, width and height of the bar observed in the model was similar to the hydrographic surveys, with depths generally ranging between 0 feet and +10 feet LWRP.

The overall width of the –10 feet LWRP contour, or navigation width, was very similar in the model as compared to the hydrographic surveys, with an average channel width of 1800 feet noted through most of the reach.

One difference observed in the model was the lack of small scour holes directly downstream of some of the dikes along the LDB. These small scour holes were the result of major flood events, which were not simulated in the model.

Overall, the trends of the model base test were very similar to the hydrographic surveys and were thus used with confidence for design alternative analysis.

3. Design Alternative Tests

All design alternatives studied in the micro model utilized the existing dike configurations in the prototype surveys. Modifications to the dikes included uprooting and notching. Some design alternatives included the addition of blunt nosed chevrons. Twelve design alternative plans were model tested to examine methods of modifying the sediment transport response trends that would create aquatic habitat diversity within this reach of the Middle Mississippi River. The effectiveness of each design was evaluated by comparing the resultant bed configuration to that of the base test. Impacts or changes induced by each alternative were evaluated by observing the sediment response of the model.

Alternative 1: *In an attempt to create a side channel within the upper portion of Dike Field 1, an existing dike was shortened and four blunt nosed chevrons were added. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *All remaining dikes unaltered.*

Plate 29 is a plan view map of the resultant bed configuration of Alternative 1. The test results indicated that this design was effective in creating a relatively fast moving, continuous side channel along the LDB. The side channel was 4500 feet in

length, from Miles 155.4 to 154.5, and between 300 feet to 500 feet in width. The depth of the side channel ranged from –20 feet to –30 feet LWRP. An adjacent bar formed to this side channel had a length of 2500 feet and width of 500 feet. Some slight shoaling was observed in the navigation channel, near Mile 155.2, with depths between –10 feet and -4 feet LWRP. The navigation channel was constricted to 1200 feet as a result of the chevron construction. The overall bathymetry of this alternative remained similar to the base test. Some areas of the thalweg appear to be slightly deeper, most notably along the RDB near Mile 154.6

Alternative 2: *The addition of four chevrons and the shortening of a dike were implemented to develop a side channel at Dike Field 1. A second side channel was attempted at Dike Field 2 by shortening an existing dike and adding three blunt nosed chevrons. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *All remaining dikes unaltered.*

Plate 30 is a plan view map of the resultant bed configuration of Alternative 2. Results from the micro model showed that a continuous side channel formed along the LDB in Dike Field 1 from Miles 155.4 to 154.4. This side channel was 6000 feet in length, 250 feet in width and had depths ranging from –10 feet to –30 feet LWRP. A 2500 feet long bar formed adjacent to the side channel with a width of 300 feet. Some shoaling occurred in the navigation channel, near Mile 155.3, with depths between –10 feet and 0 feet LWRP. The width of the navigation channel decreased to 1200 feet near Mile 155.4 as a result of the added chevron structures. A second side channel developed along the RDB at Dike Field 2. The flow of this side channel was relatively slower than the first side channel. The second side channel had a length of 3000 feet, width of 200 feet and depth of –10 feet LWRP. The bar that formed adjacent to this side channel had a length of 2000 feet and a width of 200 feet. Additional slight shoaling occurred in the navigation channel, near Mile 152.2, with depths between –10 feet and -4 feet LWRP. Due to the placement of the blunt nosed chevrons the navigation channel was constricted to 1100 feet near Mile 154.4. The overall bathymetry of this alternative, including the location and depth of the thalweg along this stretch of the channel remained similar to the base test.

Alternative 3: *In an effort to create two separate side channels, a series of four blunt nosed chevrons and a dike was shortened in Dike Field 1 and three blunt nosed chevrons a dike was notched and a dike was shortened in Dike Field 2. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*

- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *Dike 153.7 R: 470 feet in length, 150-foot notch located 250-feet from the bank line.*
- *All remaining dikes unaltered.*

Plate 31 is a plan view map of the resultant bed configuration of Alternative 3. Test results show that continuous side channels formed in Dike Field 1 as well as Dike Field 2. The initial side channel had a length of 4800 feet, width of 500 feet and a depth that ranges between –10 feet and –30 feet LWRP. The depositional bar that formed adjacent to this side channel had a length of 2500 feet and a width of 300 feet. Some shoaling occurred in the navigation channel, near Mile 155.5, with depths between –10 feet and 0 feet LWRP. The width of the navigation channel constricted to 1200, near Mile 155.4. Some additional shoaling was observed in the navigation channel, near Mile 155.2, with depths between –10 feet and 0 feet LWRP. The second side channel along RDB in Dike Field 2 had a length of 2500 feet, a width of 200 feet and a depth that ranged from –10 feet to –30 feet LWRP. The width of the navigation channel was constricted to 1200 feet near Mile 154.4 due to the added structures. The bar that formed adjacent to the second side channel was 2000 feet in length and 200 feet in width. The location and depth of the thalweg and the overall bathymetry of this alternative were comparable to the base test.

Alternative 4: *In an attempt to create a side channel within the upper portion of Dike Field 1, one existing dike was shortened and four blunt nosed chevrons were added. A second side channel formation was attempted at Dike Field 2 by shortening an existing dike, notching another and adding three blunt nosed chevrons. The creation of a third side channel was attempted within the middle section of Dike Field 1 by uprooting two existing dikes, shortening another and adding a blunt nosed chevron. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *Mile 153.15: 150-foot by 150-foot blunt nosed chevron centered at 300-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 153.6 L: shortened to 250-feet in length.*
- *Dike 153.0 L: 350 feet in length, made rootless from 0 to 150-feet from the bank line*
- *Dike 152.5 L: 400 feet in length, made rootless from 0 to 200 feet from the bank line.*
- *All remaining dikes unaltered.*

Plate 32 is a plan view map of the resultant bed configuration of Alternative 4. Results from the micro model test indicated continuous side channels formed in Dike Field 1 and Dike Field 2. The side channel that developed along Dike Field 1 had a length of 5000 feet, a width of 400 feet and depth that ranged between –10 feet and –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 2000 feet and a width of 450 feet. As a result of the additional structures the navigation channel constricted to 1200 feet near Mile 155.4. The side channel located along Dike Field 2 had a length of 3000 feet, width of 300 feet and a depth that ranged from –10 feet to –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 1500 feet and width of 200 feet. Due to the placement of new structures the navigation channel near Mile 154.4 was constricted to 1100 feet. The attempt to create a third side channel was unsuccessful. A semi-side channel formed along the LDB in Dike field 3 near Mile 153.0. This channel had a length of 1200 feet, a width of 300 feet and a depth that ranged between –10 feet to –30 feet LWRP. The channel ended abruptly along the LDB near Mile 152.8. Some slight shoaling was observed in the navigation channel, near Mile 153.2, with depths between –10 feet and -8 feet LWRP. The navigation channel width remained 1900 feet near Mile 152.0. Comparing the alternative to the base test additional scouring was found along RDB near Mile 154.6 and Mile 151.5. Aside from these two locations the overall bathymetry of this alternative and thalweg location remained consistent with the base test.

Alternative 5: *In an effort to create aquatic diversity a series of side channels were attempted. Four blunt nosed chevrons were added and an existing dike was shortened in the upper portion of Dike Field 1 and three blunt nosed chevrons and an existing dike was shortened in Dike Field 2 to try to create side channels. The development of a third side channel was attempted within the middle section of Dike Field 1 by shortening, uprooting and notching existing dikes. Two blunt nosed chevrons were also added to this section. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *Mile 153.3: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 153.15: 150-foot by 150-foot blunt nosed chevron centered at 300-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 153.6 L: shortened to 250-feet in length.*
- *Dike 153.0 L: 350 feet in length, made rootless from 0 to 150-feet from the bank line.*
- *Dike 152.5 L: 600 feet in length; 200-foot notch located 200 feet from the bank line.*
- *All remaining dikes unaltered.*

Plate 33 is a plan view map of the resultant bed configuration of Alternative 5. Test results indicated continuous side channels along the upper portion of Dike Field 1 and Dike Field 2 were successful. The attempt to create a continuous side channel along the middle portion of Dike Field 1 was somewhat successful. The side

channel that formed along the upper portion of Dike Field 1 had a length of 4500 feet, width of 500 feet and a depth that ranged between –20 feet to –30 feet LWRP. The bar formation adjacent to this side channel had a length of 2500 feet and width of 500 feet. The navigation channel was constricted to 1200 feet from 1800 feet near Mile 154.4 as a result of the placement of the new structures. Some slight shoaling was observed in the channel near Mile 155.2, with depths between –10 feet and –4 feet LWRP. The side channel that formed along Dike Field 2 along the RDB had a length of 3500 feet, a width of 150 feet and a depth that ranged between –10 feet to –20 feet LWRP. The bar that formed adjacent to this side channel had a length of 2000 feet and a width of 300 feet. The navigation channel width was constricted to 1100 feet due to the chevron placement. The final side channel started along the LDB near Mile 153.1 and continued through a notch in Dike 152.5L. This side channel had a length of 3000 feet and a width of 300 feet. The bar formation adjacent to this side channel had a length of 3000 feet and a width of 300 feet. The navigation channel remained 1800 feet in width along the middle section of Dike Field 1. The thalweg location and overall bathymetry remained similar between the base test and alternative five.

Alternative 6: *The formation of a side channel was attempted in the upper portion of Dike Field 1 by adding four blunt nosed chevrons, shortening an existing dike and notching another. A second side channel was attempted in Dike Field 2 by adding a series of three blunt nosed chevrons and shortening an existing dike. The formation of a final side channel in the middle section of Dike Field 1 was attempted by adding three blunt nosed chevrons, notching two existing dikes while shortening and notching two other dikes. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*

- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *Mile 153.3: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 153.15: 150-foot by 150-foot blunt nosed chevron centered at 300-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.2: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 153.6 L: shortened to 250-feet in length.*
- *Dike 153.0 L: 350 feet in length, made rootless from 0 to 150-feet from the bank line.*
- *Dike 152.5 L: 600 feet in length; 200-foot notch located 200 feet from the bank line.*
- *Dike 152.1 L: 780 feet in length; 200-foot notch located 350 feet from the bank line.*
- *All remaining dikes unaltered.*

Plate 34 is a plan view map of the resultant bed configuration of Alternative 6. Micro model test results indicated that this design alternative was successful in creating three side channels. A 5000 feet long continuous side channel formed along LDB from Mile 155.3 to Mile 154.4. This side channel had a width of 300 feet and a depth

that ranged between –10 feet to –30 feet LWRP. The bar that formed adjacent to the side channel had a length of 2500 feet and width of 400 feet. The navigation channel was constricted from 1800 feet to 1200 feet near Mile 155.4 due to the additional structures placed in the channel. A second side channel was created along Dike Field 2 along RDB from Miles 154.3 to 153.8. This side channel was continuous and had a length of 3000 feet, a width of 200 feet and a depth that ranged between –10 feet and –20 feet LWRP. The bar formation adjacent to the side channel had a length of 1500 feet and a width 0f 250 feet. The width of the navigation channel was reduced to 1100 feet from near Mile 154.4 due to the placement of new structures. The final side channel formed along the LDB from Mile 153.2 to Mile 151.9. This side channel had a length of 8000 feet a width 200 feet and depths that ranged between –10 feet to –30 feet LWRP. The bar formation adjacent to this side channel was 6500 feet in length with a width of 300 feet. Some shoaling was observed in the navigation channel near Miles 153.0 and 152.2, with depths between –10 feet and –2 feet LWRP. The navigation channel was constricted to 1200 feet near Mile 152.0. The overall bathymetry of this alternative and the location of the thalweg were similar to the base test.

Alternative 7: *In an attempt to create a continuous side channel within the upper portion of Dike Field 1, four blunt nosed chevrons were added, an existing dike was shortened and another was notched. A second side channel was attempted in Dike field 2 by placing three blunt nosed chevrons along the RDB and shortening an existing dike. Two additional side channels were attempted along the LDB near Mile 153.0 and 151.3. Three blunt nosed chevrons were added, three existing dikes were notched and a dike was made rootless to try to achieve this alternative. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*

- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *Mile 153.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 153.6 L: 570 feet in length, 200-foot notch located 200-feet from the bank line.*
- *Dike 153.0 L: 350 feet in length, made rootless from 0 to 250-feet from the bank line.*
- *Dike 152.5 L: 600 feet in length; 200-feet notch located 200 feet from the bank line.*
- *Mile 151.3: 150-foot by 150-foot blunt nosed chevron centered at 900-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 151.1: 150-foot by 150-foot blunt nosed chevron centered at 550-feet from the LDB, placed at +15 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 35 is a plan view map of the resultant bed configuration of Alternative 7. Test results indicated that this design was effective in creating a continuous side channel along the LDB from Miles 155.4 to 154.5. This side channel had a length of 4500 feet, a width of 350 feet and a depth that ranged between –10 feet to –30 feet LWRP. The bar formation that developed adjacent to this side channel had a length

of 3000 feet and a width of 450 feet. The width of the navigation channel near Mile 155.4 constricted to 1200 feet. A second continuous side channel was created along the RDB near Mile 154.3. This side channel length was 4000 feet, with a width of 250 feet and had depths that ranged between –10 feet and –30 feet LWRP. The bar formation adjacent to this side channel was 2000 feet long and had was 200 feet wide. The navigation channel constricted to 1100 feet near Mile 154.4 due to the placement of the chevron structures. A third side channel developed along the LDB near Mile 152.9. This channel had a length of 2000 feet, a width of 200 feet and a depth that ranged between –10 feet and –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 1200 feet and a width of 150 feet. The attempt to create a fourth side channel was unsuccessful. The placement of two additional chevrons and the notching of an existing dike created an area of scouring near Dike 151.0L. The minimum width of the navigation channel through the lower section of this reach was 1300 feet. The overall bathymetry of this alternative was comparable to the base test with the exception of the additional areas of scouring located near Mile 154.0 and along the RDB near Mile 152.0. The depth and location of the thalweg was consistent with the base test.

Alternative 8: *The development of a continuous side channel in Dike Field 1 was attempted by adding four blunt nosed chevrons, shortening an existing dike and notching another. Another continuous side channel was attempted along RDB in Dike Field 2 by the addition of three chevrons and the shortening of an existing dike. The creation of a third side channel was attempted within the middle section of Dike Field 1 by uprooting and notching existing dikes as well as three blunt nosed chevrons. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*

- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Dike 154.6 L: 650 feet in length, 200 foot notch located 300-feet from the bank line.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *Mile 153.2: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.2: 150-foot by 150-foot blunt nosed chevron centered at 500-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 151.7: 150-foot by 150-foot blunt nosed chevron centered at 500-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 153.6 L: 570 feet in length; 200-foot notch located 200-feet from the bank line.*
- *Dike 153.0 L: 350 feet in length, made rootless from 0 to 250-feet from the bank line.*
- *Dike 152.5 L: 600 feet in length, 200-feet notch located 200 feet from the bank line.*
- *Dike 152.1 L: 780 feet in length, 200-feet notch located 250 feet from the bank line.*
- *Dike 151.3 L: 840 feet in length, 200-feet notch located 400 feet from the bank line.*
- *All remaining dikes unaltered.*

Plate 36 is a plan view map of the resultant bed configuration of Alternative 8. Micro model tests showed successful results in the development of a continuous side channel along the LDB from Miles 155.4 to 154.5. This side channel had a length of 4500 feet, a width of 250 feet and a depth that ranged between –10 feet to –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 2000 feet and a width of 200 feet. Some slight shoaling was observed in the navigation channel near Mile 155.3, with depth between –10 feet and –4 feet LWRP. The navigation channel constricted to 1200 feet near Mile 154.4. A second side channel was created along the RDB near Mile 154.4. This side channel had a length of 4000 feet, a width of 250 feet and had a depth that ranged between –10 feet to –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 2500 feet and a width of 200 feet. The width of the navigation channel constricted to 1100 feet due to the placement of chevrons. The final side channel developed along the LDB near Mile 153.0 and continued 7000 feet to Mile 151.5. This side channel was not continuous with a width of 300 feet and a depth that ranged from –10 feet to –30 feet LWRP. Two bars formed adjacent to this side channel, the first began near Mile 153.0 and was 3000 feet in length and had a width of 150 feet. The second bar began near Mile 152.3 and continued 3500 feet. The width of this bar was 200 feet. Additional scouring was located behind notched Dike 151.3 L. The navigation channel width constricted to 1400 feet near Mile 152.0 due to the placement of the chevrons. Overall bathymetry of this alternative was comparable to the base test except for the additional scouring in the thalweg near Mile 154.3, near Dike 153.6 Land along the RDB near Mile 152.3. With the exception of the mentioned scouring locations, the thalweg properties of the alternative test were similar to the base test.

Alternative 9: *In an attempt to create a side channel along LDB within the upper portion of Dike Field 1, four blunt nosed chevrons were added, an existing dike was shortened and another was notched. A second side channel was attempted along RDB in Dike Field 2 by adding a three blunt nosed chevrons and shortening an existing dike. A final side channel was attempted along LDB in the middle to lower*

section of Dike Field 1. This design added four blunt nosed chevrons, notched four existing dikes and made rootless another. Dike heights were unaltered.

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Dike 154.6 L: 650 feet in length, 200 foot notch located 300-feet from the bank line.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *Mile 153.2: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.4: 150-foot by 150-foot blunt nosed chevron centered at 550-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.15: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.0: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 151.3: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*

- *Dike 153.6 L: 570 feet in length, 200-foot notch located 200-feet from the bank line.*
- *Dike 153.0 L: 350 feet in length, made rootless from 0 to 250-feet from the bank line.*
- *Dike 152.5 L: 600 feet in length, 200-foot notch located 200 feet from the bank line.*
- *Dike 152.1 L: 780 feet in length, 200-foot notch located 250 feet from the bank line.*
- *Dike 151.3 L: 840 feet in length, 200-foot notch located 400 feet from the bank line.*
- *All remaining dikes unaltered.*

Plate 37 is a plan view map of the resultant bed configuration of Alternative 9. Micro model test results indicated that a continuous side channel formed along the LDB near Mile 155.3 and continued 4500 feet. This side channel had a width of 250 feet and a depth that ranged between –10 feet to –30 feet LWRP. The bar formation adjacent to this side channel was 2000 feet in length and had a width of 200 feet. Some shoaling was observed in the navigation channel, near Mile 156.2, with depths between –10 feet and 0 feet LWRP. Additional shoaling occurred in the navigation channel near Mile 155.4, with depths near 0 feet LWRP. The navigation channel near Mile 155.4 constricted to 1200 feet. A second side channel formed along RDB near Mile 154.4. This side channel was continuous and had a length of 4000 feet, width of 250 feet and a depth that ranged between –10 feet to –30 feet LWRP. The bar that formed adjacent to this side channel was 2500 feet in length and had a width of 200 feet. The navigation channel width was constricted to 1100 feet near Mile 154.4 as a result of the placement of chevrons. The final side channel began along the LDB near Mile 153.0 and continued 9000 feet to Mile 151.3. This side channel was continuous and had a width of 200 feet and a depth that ranged between –10 feet and –30 feet LWRP. Two separate bars formed adjacent to this side channel. The first bar began near Mile 153.0 and continued to 152.5. This bar had a length of 2200 feet and a width of 200 feet. The second bar started near Mile

152.1 and continued 3500 feet to Mile 151.3. The width of this bar was 200 feet. Additional scouring was located behind Dike 151.3 L. Some shoaling was observed in the navigation channel, near Mile 152.2, with depths between –10 feet and 0 feet LWRP. The width of the navigation channel width constricted to 1400 feet near Mile 152.0. The overall bathymetry of this alternative was similar to the base test with the exception of additional scouring along the RDB near Mile 154.4, along Dike 153.6 L, along the RDB near Mile 152.2 and behind Dike 151.3 L. The location and depth of the thalweg was comparable to the base test.

Alternative 10: *The formation of a side channel was attempted in the upper portion of Dike Field 1 by adding four blunt nosed chevrons, shortening an existing dike and notching another. A second side channel was attempted in Dike Field 2 by adding three blunt nosed chevrons and shortening an existing dike. A third side channel in the middle of Dike Field 1 was attempted by adding six blunt nosed chevrons, notching three existing dikes, shortening a dike and uprooting a dike. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Dike 154.6 L: 650 feet in length, 200 foot notch located 300-feet from the bank line.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*

- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *Mile 153.5: 150-foot by 150-foot blunt nosed chevron centered at 500-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 153.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.8: 150-foot by 150-foot blunt nosed chevron centered at 500-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.3: 150-foot by 150-foot blunt nosed chevron centered at 550-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.0: 150-foot by 150-foot blunt nosed chevron centered at 700-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 151.7: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 153.6 L: shortened to 300-feet in length.*
- *Dike 153.0 L: 350 feet in length, made rootless from 0 to 250-feet from the bank line.*
- *Dike 152.5 L: 600 feet in length,200-foot notch located 200 feet from the bank line.*
- *Dike 152.1 L: 780 feet in length, 200-foot notch located 250 feet from the bank line.*
- *Dike 151.3 L: 840 feet in length, 200-foot notch located 400 feet from the bank line.*
- *All remaining dikes unaltered.*

Plate 38 is a plan view map of the resultant bed configuration of Alternative 10. Tests results indicated that this design alternative was successful in creating three separate side channels. A 4500 feet long continuous side channel formed along the

LDB from Mile 155.3 to 154.4. This side channel had a width of 300 feet and a depth that ranged between –10 feet to –30 feet LWRP. A 2500 feet long bar with a width of 400 feet formed adjacent to this side channel. The width of the navigation channel was constricted to 1200 feet near Mile 154.4 due to the additional structures placed in the channel. A second side channel developed in Dike Field 2 along the RDB from Miles 154.3 to 153.8. This side channel was continuous and had a length of 3000 feet, width of 200 feet and a depth that ranged between –10 feet to –20 feet LWRP. The bar that formed adjacent to this side channel had a length of 1500 feet and a width of 250 feet. The navigation channel width was constricted to 1100 feet near Mile 154.4 due to the placement of the chevrons. The final side channel formed along the LDB near Mile 153.0 and continued to Mile 152.1. This side channel had a length of 7500 feet, a width of 200 feet and a depth that ranged between –10 feet and –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 6500 feet and a width of 150 feet. Additional scouring located behind Dike 152.1L also occurred. Some shoaling was observed in the navigation channel, near Mile 152.2, with depths between –10 feet and 0 feet LWRP. The navigation channel width constricted to 1400 feet near Mile 152.0. The overall bathymetry of this alternative and the location of the thalweg were comparable to the base test.

Alternative 11: *In an attempt to create a continuous side channel within the upper portion of Dike Field 1, four blunt nosed chevrons with trail dikes were added, an existing dike was shortened and another was notched. A second side channel was attempted in Dike Field 2 by placing three blunt nosed chevrons along the RDB and shortening an existing dike. Six blunt nosed chevrons, three dikes were notched, a dike was shortened and another was made rootless in an attempt to create a continuous side channel along LDB in the Middle of Dike Field 1. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP, 400-foot trail dike connected to end of the chevron at +15 feet LWRP.*

- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP, 600-foot trail dike connected to end of the chevron at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP, 400-foot trail dike connected to end of the chevron at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Dike 154.6 L: 650 feet in length, 200 foot notch located 300-feet from the bank line.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*
- *Mile 153.5: 150-foot by 150-foot blunt nosed chevron centered at 500-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 153.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.8: 150-foot by 150-foot blunt nosed chevron centered at 500-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.3: 150-foot by 150-foot blunt nosed chevron centered at 550-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.0: 150-foot by 150-foot blunt nosed chevron centered at 700-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 151.7: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 153.6 L: shortened to 300-feet in length.*

- *Dike 153.0 L: 350 feet in length, made rootless from 0 to 250-feet from the bank line.*
- *Dike 152.5 L: 600 feet in length,200-foot notch located 200 feet from the bank line.*
- *Dike 152.1 L: 780 feet in length, 200-foot notch located 250 feet from the bank line.*
- *Dike 151.3 L: 840 feet in length, 200-foot notch located 400 feet from the bank line.*
- *All remaining dikes unaltered.*

Plate 39 is a plan view map of the resultant bed configuration of Alternative 11. Micro model test results indicated that this design was effective in creating a continuous side channel along the LDB from Miles 155.4 to 154.4. This side channel had a length of 5000 feet, width of 350 feet and a depth that ranged between –10 feet to –30 feet LWRP. The bar that formed adjacent to this side channel had a length 2500 feet and a width of 250 feet. The addition of the trail dikes behind the chevrons increased the overall height of the bar formation. Due to the placement of chevrons, the width of the navigation channel near Mile 155.4 constricted to 1200 feet. A second side channel was successfully created along the RDB near Mile 154.3. This side channel had a length of 400 feet, a width of 250 feet and depths that ranged between –10 feet to –30 feet LWRP. The bar that formed adjacent to his side channel had a length of 1500 feet and a width of 200 feet. The width of the navigation channel constricted to 1100 feet near Mile 154.4 due to the location of chevrons. A third side channel developed along the LDB in the middle of Dike Field 1, beginning near Mile 153.0. This side channel had a length of 3500 feet, a width of 200 feet and with depths between –10 feet to –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 3000 feet and a width of 300 feet. This side channel was not continuous and ended abruptly near Mile 152.4. The width of the navigation channel constricted to 1400 feet near Mile 152.0. The overall bathymetry of this alternative was similar to the base test with the exception of the additional scouring around the chevron along LDB near Mile 153.5,

along RDB near Mile 152.0 and along RDB near Mile 151.8. The location of the thalweg was comparable to the base test.

Alternative 12: *The formation of a side channel was attempted in the upper portion of Dike Field 1 by adding four blunt nosed chevrons, shortening an existing dike and notching another. A second side channel was attempted in Dike Field 2 by adding three blunt nosed chevrons and shortening an existing dike. A third side channel in the middle of Dike Field 1 was attempted by adding six blunt nosed chevrons, notching four existing dikes, shortening a dike and uprooting a dike. Dike heights were unaltered.*

- *Mile 155.4: 150-foot by 150-foot blunt nosed chevron centered at 800-feet from the LDB, placed at +15 feet LWRP, 400-foot trail dike connected to end of the chevron at +15 feet LWRP.*
- *Mile 155.3: 150-foot by 150-foot blunt nosed chevron centered at 875-feet from the LDB, placed at +15 feet LWRP, 600-foot trail dike connected to end of the chevron at +15 feet LWRP.*
- *Mile 155.15: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP, 400-foot trail dike connected to end of the chevron at +15 feet LWRP.*
- *Mile 155.05: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 154.9 L: shortened to 250-feet in length.*
- *Dike 154.6 L: 650 feet in length, 200 foot notch located 300-feet from the bank line.*
- *Mile 154.4: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 155.35: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the RDB, placed at +15 feet LWRP.*
- *Mile 154.2: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the RDB, placed at +15 feet LWRP.*
- *Dike 154.0 R: shortened to 250-feet in length.*

- *Mile 153.3: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 153.2: 150-foot by 150-foot blunt nosed chevron centered at 400-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 153.05: 150-foot by 150-foot blunt nosed chevron centered at 350-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.6: 150-foot by 150-foot blunt nosed chevron centered at 450-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.3: 150-foot by 150-foot blunt nosed chevron centered at 500-feet from the LDB, placed at +15 feet LWRP.*
- *Mile 152.0: 150-foot by 150-foot blunt nosed chevron centered at 600-feet from the LDB, placed at +15 feet LWRP.*
- *Dike 153.6 L: shortened to 300-feet in length.*
- *Dike 153.0 L: 350 feet in length, made rootless from 0 to 250-feet from the bank line.*
- *Dike 152.5 L: 600 feet in length,200-foot notch located 200 feet from the bank line.*
- *Dike 152.1 L: 780 feet in length, 200-foot notch located 250 feet from the bank line.*
- *Dike 151.3 L: 840 feet in length, 200-foot notch located 400 feet from the bank line.*
- *Dike 151.0 L: 780 feet in length, 150-foot notch located 400 feet from the bank line.*
- *All remaining dikes unaltered.*

Plate 40 is a plan view map of the resultant bed configuration of Alternative 12. Test results indicated that a continuous side channel was successfully created along the LDB from Miles 155.4 to 154.5. This side channel had a length of 4500 feet, a width of 250 feet and depths that ranged between –10 feet to –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 2000 feet and a width of 200 feet. Some shoaling occurred in the navigation channel, near Mile 155.4, with

depths between –10 feet and –4 feet LWRP. The width of the navigation channel constricted to 1200 feet near Mile 155.4. A second continuous side channel formed along the RDB near Mile 154.2. This side channel had a length of 400 feet, a width of 200 feet and a depth that ranged between –10 feet and –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 2500 feet with a width of 200 feet. The navigation channel constricted to 1100 feet near Mile 154.4. The final side channel formed along the LDB in the middle of Dike Field 1 near Mile 153.0. This side channel was 3500 feet in length, 200 feet in width and had a depth that ranged from –10 feet to –30 feet LWRP. The bar that formed adjacent to this side channel had a length of 3000 feet and a width of 300 feet. Some additional scouring occurred behind notched Dikes 151.3 L and 151.0 L. The navigation channel was constricted to 1200 feet from near Mile 152.0. The overall bathymetry of this alternative is similar to the base test except that additional scouring along RDB near Mile 152.0. The location of the thalweg in this survey is comparable to the base test.

CONCLUSIONS

1. Summary and Recommendations

Several alternative design tests were conducted in this particular study. Each alternative was tested with the intention of creating some form of side channel and bar formation. Additional bathymetric diversity was desired while not negatively influencing the integrity of the navigation channel.

Alternatives 1 through 3 focused on improving aquatic diversity within the upper portion of Dike Field 1 and Dike Field 2. Alternatives 4 through 12 focused on improvements within the upper portion of Dike Field 1, Dike Field 2 and the lower portion of Dike Field 1.

Alternative 1 was successful in creating a continuous side channel (side channel 1) within the upper portion of Dike Field 1. This side channel began near Mile 155.4 L and continued to Mile 154.6 L. An excellent bar formation also developed in addition to the side channel. Due to the addition of new structures, the navigation channel at this section of the reach decreased to 1200 feet. Although the channel width decreased, it was adequate for barge and other river navigation. Some slight shoaling was noted to occur in the navigation channel.

Alternative 2 was also successful in creating a slow flowing continuous side channel (side channel 2) within Dike Field 2, while continuing to maintain the integrity of side channel 1. Side channel 2 began near Mile 154.5 R and continued to Mile 153.9 R. An average island formation developed as a result of the side channel construction. The navigation channel was reduced to 1100 feet near Mile 154.4 as a result of the new structures incorporated into this design alternative. The navigation channel width was adequate and would not negatively affect navigation through this reach. Some slight shoaling was observed in the navigation channel from this alternative.

Alternative 3 was an attempt to increase the overall length of side channel 2. This was attempted by altering Dike 153.7 R. This design alternative was unsuccessful in increasing the length of side channel 2.

Alternatives 4 through 10 were combinations of Alternatives 1, 2 and 3. Developing a continuous side channel in the middle and lower portion of Dike Field 1 was the main focus of these alternatives. A combination of adding blunt nosed chevrons with dike alterations was used. Overall these alternatives were successful in creating a side channel but failed to develop a continuous channel. Alternatives 6, 8 and 9 had the best results in the form of a continuous side channel within the middle portion of Dike Field 1. Some slight shoaling was noted in the navigation channel in most of the tests. Of the three alternatives, Alternative 6 seemed to produce the most favorable trends.

Alternatives 11 and 12 were attempts to increase the depth and flow in side channels by adding trail dikes to the chevron structures. This design was applied to the chevrons in Alternatives 1 and 10. The results of these attempts were not successful.

Generally, all of the alternatives showed a tremendous potential for side channel development and new island or bar formation. All tests attempted to create bathymetric and flow diversity trough out the Herculaneum Reach. The results of most of the alternatives indicated that some very slight shoaling occurred in the navigation channel. The locations of shoaling were primarily confined to Miles 155.4 and 152.2. Therefore, a slight possibility for future dredging may be required. It is recommended that if any of the alternatives were implemented in the river, a phased construction approach would be desirable. In addition, a close monitoring program of navigation channel conditions both before and after construction should be incorporated.

2. Interpretation of Model Test Results

In the interpretation and evaluation of the results of the tests conducted, it should be remembered that the results of these model tests were qualitative in nature. Any hydraulic model, whether physical or numerical, is subject to biases introduced as a result of the inherent complexities that exist in the prototype. Anomalies in actual hydrographic events, such as prolonged periods of high or low flows are not reflected in these results, nor are complex physical phenomena, such as the existence of underlying rock formations or other non-erodible variables. Flood flows were not simulated in this study.

This model study was intended to serve as a tool for the river engineer to guide in assessing the general trends that could be expected to occur in the actual river from a variety of imposed design alternatives. Measures for the final design may be modified based upon engineering knowledge and experience, real estate and construction considerations, economic and environmental impacts, or any other special requirements.

FOR MORE INFORMATION

For more information about micro modeling or the Applied River Engineering Center, please contact Robert Davinroy, Dawn Lamm or Michael Rodgers at:

Applied River Engineering Center
U.S. Army Corps of Engineers - St. Louis District
Hydrologic and Hydraulics Branch
Foot of Arsenal Street
St. Louis, Missouri 63118

Phone: (314) 263-4714, (314) 263-8090, or (314) 263-8091
Fax: (314) 263-4166

E-mail: Robert.D.Davinroy@mvs02.usace.army.mil
Michael.T.Rodgers@mvs02.usace.army.mil
Dawn.Lamm@mvs02.usace.army.mil

Or you can visit us on the World Wide Web at:
http://www.mvs.usace.army.mil/engr/river/river.htm

APPENDIX OF PLATES

Plate number 1 through 40 follow:

1. Location and Vicinity Map of the Study Reach
2. Characteristics of the Study Reach
3. Dike Field Locations
4. 1880 Topographic and Hydrographic Survey
5. 1908 Topographic and Hydrographic Survey
6. 1929 Aerial Photograph
7. 1959 Hydrographic Survey
8. 1970 Hydrographic Survey
9. 1978 Hydrographic Survey
10. 1983 Hydrographic Survey
11. 1987 Hydrographic Survey
12. 1995 Hydrographic Survey
13. 2002 Hydrographic Sweep Survey
14. 1974 Aerial Photograph
15. 1988 Aerial Photograph
16. 1993 Aerial Photograph
17. 1996 Aerial Photograph
18. Dikes 156.0 R to 149.7 R & 150.7 L to 152.1 L
19. Dikes 152.1 L to 150.0 L & 150.6 R to 150.0 R
20. Dikes 151.8 R & 151.5 R
21. Dikes 153.6 L to 152.1 L
22. Dikes 156.0 L to 154.1 L
23. Typical Planform of RDB
24. Location of Velocity Profiles RDB
25. Typical Planform of LDB
26. Location of Velocity Profiles LDB
27. Herculaneum Micro Model
28. Base Test

29. Alternative 1
30. Alternative 2
31. Alternative 3
32. Alternative 4
33. Alternative 5
34. Alternative 6
35. Alternative 7
36. Alternative 8
37. Alternative 9
38. Alternative 10
39. Alternative 11
40. Alternative 12